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PROPFAN TYPE CERTIFICATION REQUIREMENTS

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EXECUTIVE SUMMARY

The objective of this report is to present, in general terms, the intent of the special conditions deemed necessary for type certification of propfan powered aircraft and their propulsion systems. Industry has developed these products to the point where the Federal Aviation Administration (FAA) is becoming involved in their civil certification. To prepare for this, the FAA met with manufacturers, other government agencies, and airworthiness authorities of other countries to discuss the key technologies involved, and possible certification issues. The information gathered has helped the FAA become familiar with the design concepts under consideration and enabled the FAA to evaluate current airworthiness standards with respect to civil certification of these new propulsion systems and aircraft.

Certification can be accomplished under the current set of airworthiness standards for transport airplanes, engines, and propellers. The airplane under Part 25, and the propulsion system under Part 33 (Engines) and Part 35 (Propellers) of the Federal Aviation Regulations (FAR). However, these advanced airplanes and powerplants incorporate novel and unique design features which are not adequately addressed by these regulations as they now exist. Consequently, existing standards in other regulations, such as FAR Part 35 standards for the certification of an engine with an integral propulsor, or new standards are needed to accommodate these novel design concepts to ensure that these new products achieve the level of safety intended by the existing regulations. It is anticipated that special conditions will be issued pursuant to FAR § 21.16 to address the novel or unique features incorporated in the airplane and powerplant designs. Given that the state of the art of propfan technology is continuously developing, the FAA will proceed with general rule making when it has experience sufficient to formulate detailed certification criteria of common applicability. Therefore, various special conditions may be issued to address propfan certification prior to amendment of the FAR to address the same issues.

It should be noted that applications may also be received for propulsion systems or airplanes that incorporate some, but not all, of the novel or unusual design features that typically characterize propfans. The special conditions would be adopted for those propulsion systems or airplanes to the extent that the novel or unusual design features exist.

The major issue identified is the possible hazard to the airplane resulting from the failure or release of propfan blades because there is no duct or casing surrounding the rotating blades. Since this lack of containment is also characteristic of turbo-propeller installations, an approach similar to that used for turbo-propeller powered airplane certification programs is appropriate for propfans. Thus, the primary emphasis should be on minimizing the possibility of propfan blade failure or release. Additionally, design precautions should be taken to minimize the hazards to the airplane in the event that one or more blades do fail or are released.

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INTRODUCTION

The oil crisis of the mid 1970's focused attention on the critical nature of the world petroleum supply and its important bearing on the economic, social, and political status of all nations. The long lines at gas pumps in this country drove home to everyone the fragile nature of our dependence on oil. The air transportation industry, with its singular dependence on petroleum products as an energy source, was particularly impacted by this crisis. Escalating fuel costs threatened the economic viability of the airlines and their ability to provide affordable service to the nation's air travelers and placed great emphasis on the development of fuel efficient aircraft designs. In response to the national need to reduce fuel consumption, programs were instituted aimed at achieving greater fuel efficiency through advances in airframe and engine technology. One result of this effort was the development of a new propulsion concept, combining the most favorable features of turbofan and turbo-propeller power. These new propulsion systems are commonly referred to as propfans, however, other terms such as Ultra High Bypass (UHB) and Unducted Fan (UDF) are also used to describe them.

The propfan can be considered an advanced form of the conventional aircraft turboprop powerplant since the basic propulsion principle in both is the same. That is, in both designs, some form of a gas turbine drives an unducted, multi-bladed device which imparts an acceleration to the mass of air passing through it thereby generating the thrust necessary for propelling the aircraft through the air. Only a small amount of jet thrust is produced in either design. The propfan has many features common to conventional propellers since it contains a series of unshrouded, rotating, variable pitch airfoils attached to a hub structure. Unique to the propfan concept, however, are:

a. The relatively large power output (more than twice as much as he largest turbo-propeller engines previously certified);

b. A multi-bladed, multi-stage contra-rotating propfan as compared to a turbo-propeller installation, or an unshrouded, variable-pitch, reversible, turbofan type powerplant (both use a relatively high number of blades, very thin airfoil sections, highly swept blade planforms, and high disk power loading);

c. An operating envelope of speed and altitude that is much greater than those of current turbo-propeller airplanes;

d. A pusher installation;

e. continuous exhaust impingement on the propfan blades;

f. unique hubs/blades/blade retention systems that differ significantly from conventional propellers and thus lack the conventional propeller's years of satisfactory service experience.

Because of these unique features, the unconventional airplane installation arrangements contemplated, and the necessity for civil certification, the Federal Aviation Administration (FAA) has been closely monitoring propfan developments.

The rapid advancement of propfan technology made it apparent that manufacturers would be approaching the FAA in the near future with requests for certification of this new equipment. Discussions in anticipation of these events made it clear that there were some unanswered questions regarding the proper regulations to be applied in these certification programs and the adequacy of the current regulations to substantiate the airworthiness of the new aircraft and their propfan propulsion systems. To provide answers to these questions it was first necessary for the FAA to become as familiar as possible with the actual design details of the new equipment. The FAA established a special propfan study team in 1986 to gather this knowledge and evaluate the current certification standards. The team consisted of one representative from each of the following FAA organizations: the Office of Airworthiness, the Office of Environment and Energy, the Transport Airplane Certification Directorate, and the Engine and Propeller Certification Directorate.

A meeting was hosted by the Aeronautical Industries Association (AIA) at Long Beach, CA, on August 6, 1986, to initiate a dialogue between industry and the certification authorities. Subsequently, the Director of Airworthiness (presently Director, Aircraft Certification Service) sent a letter to manufacturers and other airworthiness authorities involved in, or concerned with, propfan programs, advising of the FAA effort and asking for the opportunity to meet with them to discuss the new technology and share views on possible certification and safety issues (Appendix 1.). The response to this letter was quite favorable and consequently the team was able to visit the major aircraft, engine, and propeller manufacturers involved in propfan programs in the United States and Europe and the Airworthiness Authorities of Great Britain, France, West Germany, and the Netherlands (Appendix 2.). Specialists from each cognizant Aircraft Certification Office (ACO) accompanied the team on these visits. These visits proved invaluable in acquainting the team members with the overall status of the new technology and with the details of various propfan concepts under development or planned by the manufacturers.

The objective of this report is to present, in general terms, the intent of the special conditions deemed necessary for type certification of propfan powered aircraft and their propulsion systems.

DESIGN CONCEPTS

a. Unducted Propfans. The propfan propulsion systems as described to the study team by the various manufacturers can be characterized as geared or gearless designs. Both types are built around an unducted thrust producing device, the propulsor, which typically contains a large number of non-metallic curved blades with very thin airfoil sections and highly swept blade planforms. Both types utilize a turbine engine core for powering the propulsor. Although single stage propfans have been designed, the emphasis appears to have shifted to dual stages which rotate in opposite directions in order to gain further increases in propulsion efficiency by utilization of the single stage swirl component. The designs differ basically in the manner in which the core power is applied to the propfan blades.

The geared design transfers power through a reduction gear system to a separate propulsor module, quite similar in many respects to the conventional turbo-propeller arrangement. The propulsor module, with blades attached to and supported by a central hub, is analogous to the propeller of the turboprop system and borrows extensively from propeller design philosophy. The blade pitch change mechanism is contained within the propulsor hub. The gear system reduces the rotational speed and divides the power of the turbine core for each row of blades while providing the counter rotating drive. In the pusher design shown the team, the propulsor module is located aft of the core engine and gear system with the core engine exhaust gases exiting through a series of individual nozzle segments arranged circumferentially. The exhaust gases impinge on the propfan blades since the nozzles are located forward of them.

The gearless design, as the name implies, transfers power without a reduction gear system. The turbine engine core exhaust drives a novel low pressure turbine consisting of two separate, multistage rotors. Each row of propulsor blades is attached to, and thus driven by these rotors which rotate in opposite directions. This turbine has no conventional stator blades; the turbine blades of the aft stage rotor serves as a stator for the forward stage. This design lacks the similarity to propeller technology which the geared design possesses and in some ways is more similar to an unshrouded turbofan engine. The hub and blade retention and the pitch change mechanism are unconventional and could possibly be exposed to the high temperature environment of the turbine.

b. Ducted Fans and Propellers. Some manufacturers are also involved in designs which include a duct surrounding large propulsor blades, similar to modern turbofan practice. However, these designs will operate at much higher bypass ratios than turbofan engines and will embody some of the other advanced features of the propfan designs previously discussed. The design concepts presented to the team included fans with a single stage of blades, counter rotating blades, variable pitch blades, geared and gearless power transfer, and the fan module located forward or aft of the core. In general, these propulsion system design concepts had not progressed as far in the development cycle as the propfans previously discussed. Also, they all featured some form of containment case for the fan blades, thus alleviating one of the most important issues associated with the unducted designs. For these reasons, consideration of this class of propulsion system will be deferred until certification becomes more imminent.

c. Airplane Configurations. Airframe manufacturers are studying ways, or have active programs to integrate the new propfan technology into their products. Both wing mounted and rear mounted propfans in either tractor or pusher arrangements are contemplated. The airplane configuration currently of most interest and probably the furthest advanced development-wise is that of two unducted, ultrahigh bypass engines mounted on the rear of the airframe. The engines have the propfans located aft of the turbine core. Airplane designs further off in the future have the propfans or ducted fans positioned on the wings in either tractor or pusher configurations.

CERTIFICATION BASIS

The Federal Aviation Regulations (FAR) define the minimum requirements for civil certification of aeronautical products. The organization of these regulations reflected the traditional business arrangement of the commercial aircraft industry which is composed of independent airframe, engine, and propeller manufacturers. Each product is type certificated under a regulation written for it. Engines and propellers are separate products and are type certificated separately because of their complexity and their separability from the aircraft. Also, many certification requirements are best accomplished by the engine or propeller manufacturer in specially designed test facilities. Therefore, aircraft engines are certified under Part 33, propellers under Part 35, and transport category airplanes under Part 25 of the FAR.

The FAR provides for the issue of special conditions in those cases where the applicable airworthiness regulations do not contain adequate or appropriate safety standards because of novel or unusual design features in an aircraft, engine, or propeller. In this context, "novel or unusual design features" means novel or unusual with respect to the applicable Parts of the FAR. Since the standards contained in the FAR may lag behind industry state of the art, such design features already may be accepted industry practices. The special conditions contain safety standards needed to establish a level of safety equivalent to that established in the applicable regulation. Two types of novel or unusual design features associated with propfans were noted:

a. Those unique to new propfan powerplants and aircraft; and

b. Those adopted for or being considered for other powerplants and aircraft as well as propfans.

This report focuses mainly on the first type of design feature. The content of each special condition to be applied in any particular type certification program will be developed by the responsible Aircraft Certification Office and the accountable Aircraft Certification Directorate.

With the introduction of ultra high-bypass ratio turbofan engines and propfans, the adequacy of present airworthiness standards for propulsion systems is in question. In at least one of the design concepts, the distinction between engine and propeller is obscure. There is no separate propeller unit and it is difficult, if not impossible, to distinguish between the "engine" portion and the "propeller" portion of the powerplant. In such cases it becomes necessary to select a regulation as the basic certification vehicle with the broadest possible application to the design of the product involved. For the gearless, unducted propfan concept, FAR Part 33, the aircraft engine airworthiness standards, best meet this criterion. Part 33 would be supplemented by special conditions covering those unique design features not addressed by the basic regulation. Many of these special conditions can be drawn from FAR Part 35 which does address some propeller concepts inherent in the gearless design.

For the geared propfan concept which resembles the traditional turbo-propeller arrangement, the approach could be to grant a FAR Part 33 type certificate for the core turbine and reduction gear system combination and a FAR Part 35 type certificate for the propulsor module. Special conditions may be required for unique features and to integrate the units into a complete propulsion system. Alternately, a basic FAR Part 33 type certificate could be granted for the entire propulsion system consisting of turbine engine core, reduction gears, and propulsor module. For this approach, special conditions would be required to cover features associated with the reduction gear system and propulsor module which are not provided for in FAR Part 33.

Until the FAR are amended, the type certification basis for propfan powered transport category airplanes would be FAR Part 25 plus special conditions as necessary. These special conditions would contain additional standards because of the unique features of the propulsion system and its location on the airplane.

DISCUSSION

a. Airplane Safety and Certification Issues. Propfan powered airplanes incorporate a number of novel or unusual features. Due to these features, special conditions will be required in certain areas to ensure that the airplanes have the level of safety intended by Part 25 of the FAR. In other areas, traditional means of showing compliance with existing requirements of FAR Part 25 are inadequate or inappropriate for propfan powered airplanes. Although special conditions will not be required in those areas, new methods of showing compliance must be devised.

This discussion is predicated on the assumption that the propfan engines will be mounted in an aft-fuselage, pusher configuration as that is the only configuration for which application for type certificate has been made to date. Further consideration would have to be given for a configuration in which the plane of the propulsor blades intersects the fuselage pressure vessel.

It should be noted that applications may be received for airplanes that incorporate some, but not all, of the novel or unusual features that typically characterize propfan airplanes. The special conditions discussed herein would be applied to those airplanes to the extent the novel or unusual features exist. Conversely, there may be applications for airplanes with novel or unusual features that are not peculiar to propfan powered airplanes. Any special conditions that would be needed for such additional novel or unusual features are beyond the scope of this discussion. Possible installations of propfans on non-transport category airplanes are also beyond the scope of this discussion.

The novel or unusual design features of the propfan powered airplanes and the associated safety issues include the following:

1. Aft-fuselage mounted propfan.

(1) Ground clearance - FAR § 25.925(a) requires certain minimum clearances between each propeller and the ground with the airplane in the level flight attitude. With the aft-fuselage mounted propfan, rotation for takeoff or landing is a more critical attitude insofar as ground clearance is concerned. Unlike typical propeller driven airplanes, a normal roll condition could aggravate this condition even further. A special condition is, therefore, needed to require appropriate minimum clearances between the propfan and the ground when the airplane is pitched up to the angle where the tail skid or aft fuselage is touching the ground, and the airplane is rolled to the greatest extent expected during takeoff or landing.

(2) Foreign Object Ingestion - The ingestion of foreign objects in flight, other than birds, is not a concern with conventional turbo-propeller powered airplanes because the propellers of such airplanes are not located behind any source of such foreign objects. Although there are sources of such objects located ahead of aft-mounted turbojet engine installations, current requirements of FAR Parts 25 and 33 provide an adequate level of safety. (Note that turbofan engines are considered "turbojet" engines insofar as compliance with FAR Part 25 is concerned.) Due to the much larger target size of a propfan and the possible consequences of blade failure, special consideration must be given to propfan-powered airplanes in this regard. A special condition is necessary to ensure that there are no airplane components subject to loss, e.g., access panels, tire treads, etc., which are located ahead of the propfan and which are larger than those ingested or otherwise accounted for during the FAR Part 33 and/or FAR Part 35 certification of the propfan. Similarly, there must be no source of pieces of shed ice that are larger than those tested, or otherwise accounted for, in the propfan certification program.

(3) Turbofan vs. Turboprop - FAR § 25.145(c) makes a distinction between turbo-propeller and turbojet powered airplanes because of the beneficial effect that the propeller wash over the wing has on the power-on stalling speed. Since there will be no such wash over the wings of airplanes with aft-mounted propfan engines, a special condition is needed to clarify that propfan powered airplanes must comply with the requirements of § 25.145(c) applicable to turbojet powered airplanes.

(4) Depending on the configuration of the propfan powerplant, the airplane must comply with either the instrument requirements of § 25.1305(d) for turbojet-powered airplanes or those of § 25.1305(e) for turbopropeller-powered airplanes, as appropriate. A special condition is needed for each engine installation to clarify which instrument requirements are applicable for the installation of that particular engine.

2. Pusher installation.

(1) There have been a number of incidents involving the loss of an engine cowl door from turbojet powered transport category airplanes. While none of these incidents has resulted in an accident, the potential for catastrophic consequences exists. The FAA is, therefore, proposing an amendment to FAR Part 25 that would provide improved cowling retention by adding specific design requirements for cowling retention systems. Due to the location of the propfan behind the cowling, the loss of a cowl door from a propfan-powered airplane has even greater potential for catastrophic consequences. In the event the amendment to FAR Part 25 has not been adopted by the time a propfan-powered airplane is presented for type certification, special conditions would be needed to provide adequate standards in this regard.

(2) Because of the pusher configuration, the propfan would be exposed to impingement of flames during an uncontained engine fire. A special condition should be proposed to ensure that the propfan blades and blade retention systems have sufficient fire integrity to allow detection of the fire and safe shut-down of the engine prior to any blade failure. The use of fire detection systems in areas surrounding the blade retention systems may be considered in determining that the engine can be safely shutdown prior to any blade failure.

(3) The propfan blades and blade retention systems of some proposed propulsion units are continuously exposed to impingement of hot, corrosive exhaust gases during normal operation. If the propulsion unit is certificated as an integral unit, a special condition should be adopted as part of the FAR Part 33 engine certification process to ensure the capability of the propulsor to operate continuously in an exhaust environment. If, on the other hand, the propulsor module is certificated as a separate entity under FAR Part 35, it may not be known at the time of certification that it will operate in this environment. Unless the capability of the propulsor to operate continuously in an exhaust environment is addressed as part of the certification, it will be necessary to adopt a special condition as part of the FAR Part 25 certification of the airplane to ensure integrity of the propulsor under these conditions.

3. Speed/altitude operating envelope.

(1) There are a number of areas in FAR Part 25 in which the requirements for turbojet powered airplanes differ from those for turbo-propeller powered airplanes. Some of these differences are due to the

much larger envelopes of speed and altitude in which turbojet powered airplanes typically operate. Because the propfan powered airplanes are intended to operate in these larger envelopes, a special condition is needed to clarify that they must comply with the same requirements as turbojet powered airplanes in these areas. In other areas, the special condition would clarify that a propfan powered airplane must comply with the FAR Part 25 requirements applicable to turbo-propeller powered airplanes.

(2) Similar distinctions are made in FAR Parts 91, 121, 125 and 135 between the operational requirements applicable to turbo-propeller powered airplanes and those applicable to turbojet powered airplanes. Some form of regulatory action should be taken to clarify which requirements of those parts are applicable to propfan powered airplanes.

4. Counter-rotating, multi-blade propfans. The means currently required to protect turbojet powered airplanes from catastrophic blade failure or release differ from those currently required for turbo-propeller powered airplanes. § 33.94 requires that failed or released fan blades must be contained within the engine. Because turbo-propeller installations have no shrouds or other means of containment, the necessary level of safety is achieved by taking design measures that minimize the possibility of propeller blade failure or release. Notwithstanding the requirements to contain fan blades or minimize the possibility of propeller blade failure or release, § 25.571(e)(2) further specifies that the airplane must be able to withstand the structural damage likely to occur from the impact of a fan or propeller blade. Due to the recent adoption of this section and the granting of exemptions, no turbo-propeller powered airplanes have been required to show compliance with § 25.571(e)(2) to date. Each of six petitioners for exemptions asserted that § 25.571(e)(2) contains an unrealistic requirement with which no economically viable propeller driven airplane could comply. In lieu of complying with this section, each of the petitioners proposed to take design precautions to minimize the hazards to the airplane in the event a blade fails or is released. In reviewing the petitions, the FAA found that structural failure due to the impact of a blade was the failure mode in only 2 of the 106 blade release events that are known to have occurred world-wide since World War II with transport category or comparable airplanes. The majority of the events were not catastrophic. For those that were catastrophic, structural damage due to the extreme unbalance created by the missing blade or damage to vital systems due to impact of the blade was the predominant failure mode. For this and other reasons discussed in the exemptions, each of the exemptions was granted. A corresponding amendment to Part 25 has been proposed (Notice 84-21; 49 FR 47358; December 3, 1984). As proposed by each of the petitioners, each exemption was granted on the condition that design precautions must be taken to minimize the hazards to the airplane in the event a blade fails or is released. While it was not necessary to ensure that the airplane could withstand the structural damage likely to occur from the most adverse blade impact, as would have been required by § 25.571(e)(2), each petitioner had to show that the structure was designed, to the extent feasible, to withstand the impact of a blade. In addition, the

petitioners had to consider the impact of the blade on vital systems and the capability of the airplane structure to survive the severe unbalance that would result from the loss of a blade.

Because there are no shrouds or casings to contain failed or released propfan blades, it will be necessary to use the same approach as that used for turbo-propeller powered airplanes. As with propellers, the primary emphasis must be on minimizing the possibility of propfan blade failure or release. Also, design precautions must be taken to minimize the hazards to the airplane in the event one or more blades do fail or are released. Whether one blade must be considered, or more than one, would depend on the possible failure modes of the particular propfan in question. As with the exemptions discussed above, the impact of the blade or blades on vital systems and the capability of the structure to survive the severe unbalance created by the missing blade or blades would have to be considered in addition to the impact of a blade or blades on structure. Although it currently is not considered feasible to design the airplane to withstand the impact of a failed or released propfan blade, it is feasible to design the airplane to withstand the likely structural damage that would occur as a result of the impact of a blade fragment or objects likely to be deflected by the propfan blades. A special condition to that effect would be appropriate. The size of fragment that would have to be considered would depend on the likely failure mode of the particular blade design used.

5. Airstart envelope. Because propfan powered airplanes may not have the inherent restart capability of typical turbojet and turbo-propeller powered transport category airplanes, a special condition is needed to require that the airplane must have in-flight restart capability when all engines are inoperative and that the airplane must have an airstart envelope of reasonable airspeed and altitude ranges when another engine is operative.

6. Flutter. The current state of the art in analysis and testing for whirl mode evaluation may be insufficient to meet the requirements of § 25.629 for propfan powered airplanes due to the pusher configuration, the high tip speeds, and the flexible propfan blades. Traditional analyses used to show freedom from whirl mode flutter are usually based on an assumption of rigid blades in a tractor configuration. The assumption of rigid blades simplifies the whirl mode analysis because thrust and drag forces appear to be insignificant. Flapping and torsional flexibility, especially with the scimitar shaped blades that will be used in the propfans, may make the effects of thrust, drag and propeller orientation significant. Flexibility in the propfan plane will raise the problem of pure mechanical instability which had historically occurred only on helicopter blades (i.e. ground resonance). In the case of the propfan powered airplanes, the propeller unsteady aerodynamic derivatives associated with the helical wake at very high tip speeds may not be predictable by current methods without experimental validation. This affects the problem of individual blade flutter as well as propfan whirl flutter. The pusher installation is a configuration that has not been subjected to a serious whirl mode investigation. While it appears that

the current objective requirements of § 25.629 will ensure freedom from whirl mode flutter, methods of analysis will have to be validated by testing to show that propfan powered airplanes comply with these requirements.

7. Cabin noise and sonic fatigue. Cabin interior noise is not addressed by FAR Parts 25 or 36 except indirectly by the requirement in FAR Part 25 that the flight crew be able to perform their duties without unreasonable concentration or fatigue. While cabin noise is of prime concern to the manufacturers, operators, and passengers, there evidently was no need to develop standards for cabin noise because an airplane would not be commercially viable if cabin noise was so severe as to present unusual annoyance or constitute a health hazard to the occupants. The same reasoning applies to propfan powered airplanes so the FAA does not anticipate a need to develop any regulatory criteria for cabin interior noise at this time.

The noise generated by the propfans has the potential for exciting parts of the aircraft structure resulting in sonic fatigue. The FAR Part 25 has provisions concerning sonic fatigue strength and structural clearance and vibration which apply equally to propfan installations. These provisions are considered adequate for certification of propfan aircraft.

b. Propulsion Safety and Certification Issues

1. Propulsor Blade/Retention System Strength Margins. From a practical perspective, attainment of a prime-reliable rotating structure cannot be assured, considering all reasonable failure scenarios, including those resulting from manufacturing defects and potential maintenance induced anomalies. However, the likelihood of a failure can be significantly reduced by the incorporation of conservative strength margins during product design. These safety factors not only provide ample strength margins for all normally anticipated operating conditions, but they also imply a degree of tolerance to the unexpected abnormalities which may occur during the product service life.

In recognition of the potential consequences of a propeller blade loss or hub failure, for example, FAR Part 35 requires demonstration of strength margin by requiring the structure to withstand a radial load equal to twice the centrifugal load attained at maximum propeller speed and a fatigue limit evaluation of all primary structures, i.e., hub, blade, and blade retention. These requirements do not necessarily reflect a specific failure condition, or combination of discrete failure events, but do verify the existence of high strength margins in the structure which desensitize the blade/retention system to unexpected anomalies or unusual service events. Propeller blade/retention system service failure data suggest that this conservative requirement is a contributory factor in achieving the respectable failure rates associated with these components. Accordingly, the ultra high-bypass powerplant certification program should incorporate tests which subject the Propfan blade/hub/retention system to both radial load (equal to twice the centrifugal load obtained at maximum blade rotational speed) and fatigue tests as are currently conducted under

FAR Part 35. The absence of this requirement in Part FAR Part 33 will necessitate issuance of a special condition if FAR Part 33 is the sole certification requirement.

The subject tests may be conducted in a static rig configuration, with component temperatures representative of a takeoff power condition. The individual rotor systems should be subjected to the load, but it is feasible that a single rotor test may be sufficient if the rotor design details and load-path characteristics are similar. The tests should be conducted at a reasonable load/unload rate, with a 1 minute dwell at the maximum load. Subsequent analytical disassembly should not reveal evidence of cracks, permanent deformation, or any conditions indicative of imminent failure.

2. Blade-Loss/Unbalance Test. The design features associated with the propfan propulsor system have resulted in the generation of several specific engine certification requirements, as described within this report. Satisfaction of these requirements establishes a conservative certification basis and should ensure sufficient strength margins for the various elements of the propulsor system. Nevertheless, the propulsor blade cannot be regarded as infallible considering the numerous anomalies which can occur over the projected service life. The FAA believes that the shroudless propulsor design can be certificated and reliably operated and maintained with low probability of failure, but that the consequences of a blade failure must be fully understood and demonstrated during the certification program.

For this reason a propulsor blade-loss test should be imposed on the propfan engine manufacturers. Such a test is necessary to provide insight to the degree of protection required by the airframe manufacturer, and demonstrates the secondary engine effects induced by the resultant propulsor imbalance. The test conditions for the propfan blade-loss test should be predicated on rig testing and analysis which identifies the most critical operating condition. Specifically, the test should reflect combinations of reasonable critical conditions such as engine power level, rotor speed, blade pitch (considering different collective pitch between rotors, if this is possible), and reverse operation.

A blade-loss test is deemed necessary for the propfan products because of their novel design features, especially the two stage, counter-rotating aspects of the design. A blade loss test for conventional propeller designs is not envisioned because of the long history of satisfactory service experience with these designs.

3. Propulsor Blade Environmental Testing. The propulsor blades envisioned are characterized by unconventional section properties incorporating swept planform airfoils constructed of composite materials. The certification program should require a thorough structural evaluation of the propulsor blade, encompassing flutter, vibration, impact tolerance, etc. Also, assessment of exposure to various environmental elements is equally significant due to the potential for degradation of the material properties. Accordingly, environmental testing should be conducted to

evaluate whether the composite material properties are degraded as a consequence of exposure to the various natural phenomena including humidity, ultraviolet radiation, temperature extremes, moisture, and lightning.

Additional testing should be conducted to evaluate the durability and erosion resistance of impermeable surface treatments intended to inhibit penetration of the composite laminates if used. Installation of the propfan powerplant in the tail-mounted configuration will likely result in high rates of debris ingestion during takeoff and landing phases, due to the large propulsor blade diameter, high mass flow, and relative alignment with the landing gear. These factors may induce high blade surface erosion rates and expose the composite material to direct environmental attack.

Compliance may be based upon prior field experience with identical or similar materials and component testing.

4. <u>Exhaust Gas Exposure</u>. Preliminary discussions with propfan powerplant manufacturers have indicated the possibility of direct exhaust gas impingement on the propulsor blades. Obviously, this may introduce a severe thermal operating environment for the blades, which is further aggravated by transient exposure during aborted starts, engine surges, high power reverse operation, and impact with certain engine-induced foreign objects (particles such as ceramic coatings, burner liner surface treatments, abradable airseal materials, etc.). The engine certification program should adopt testing which assesses these normal and abnormal operating conditions.

The tail-mounted arrangement of propfan powerplants also exposes the propulsor blades to nacelle drainage fluids such as oil, fuel and hydraulic fluid. The compatibility of the propulsor blade composite material with such chemicals requires evaluation during the engine certification program. Previous service experience with identical or similar materials and/or component testing may serve to demonstrate the impact of such chemical exposure.

5. <u>Foreign Object Ingestion</u>. Foreign object ingestion is an issue which, justifiably, has attracted considerable attention relative to the propfan powerplant. Preliminary information presented to the FAA has indicated propulsor designs will incorporate large blade diameters and high solidity ratios, non-metallic blade construction, unducted counter-rotating rotors, and variable pitch blades having no part-span shrouds to provide tangential load dispersal. Considering these features, the momentum transfer attendant with a significant ingestion event appears to increase the potential for damage in the propfan powerplant. Therefore, in addition to the tests prescribed in § 33.77, the propfan engine certification program should consider the following concerns, and conduct tests (or a single test to substantiate the worst case) to demonstrate ingestion of the following objects:

Nacelle Doors/Panels. Nacelle doors/panels are considered objects which can reasonably be expected to be ingested, particularly due to the large propulsor blade diameter and its plane of rotation aft of the nacelle. Larger objects such as flaps/slats are infrequently liberated, and are considered an unreasonable test requirement to be imposed on the engine manufacturers. Nevertheless, it is recommended that the aircraft certification program assess the retention features of various upstream lift devices as a means of further reducing the probability of release of these components. However, nacelle doors/panels are more prone to liberation due to human error (improper latching, neglect, etc.). For this reason, it is recommended that the engine certification program employ an ingestion test of a reasonable nacelle panel/door element. Component geometry structure and size, among other details, must be coordinated with the appropriate Aircraft Certification Office(s). Issuance of a Special Condition would be necessary to implement such a test into the engine certification requirements.

Tire Treads. Turbofan service experience and certification testing has indicated that ingestion of segments of ruptured aircraft tire treads is within the scope of damage incurred by ingestion of a 4 lb. bird, and that the dynamic and kinematic reactions of the rotor system to such events are analogous. Accordingly, tire tread ingestion testing has not been imposed on engine manufacturers during recent certification programs. However, this correlation and similarity has not yet been determined for the propfan powerplants, and it is recommended that tire tread ingestion testing be incorporated into the engine certification program. Determination of the size and geometry of tire tread segments for the subject test should be predicated on a review of an appropriate statistical database comprising details of runway tire tread debris.

Ice. Airframe and engine manufacturers have suggested that airframe manufacturers may adopt a wing deicing feature which relies on electromagnetic pulsations on the leading edge to liberate ice accretion rather than inhibit its formation via a conventional bleed-air plenum system. This deicing system introduces unique interface considerations for any tail-mounted powerplant, but these concerns are compounded with the propfan due to its large diameter, high solidity ratio and use of non-metallic blade materials. Such a system will require assessment of the impact of continuous ingestion of small ice fragments (in engine core and propulsor blades) during the engine certification program.

A viable approach to certification of this feature is to establish and identify, in the engine installation instructions, a description of the tolerable size of ice fragment which can be continuously ingestion without incurring unacceptable engine damage. Thereafter, the cognizant aircraft certification authorities would use this information to verify the suitability of the wing deicing systems with regard to this demonstrated threshold. These evaluations should consider the situation where an inadvertent delay in system activation causes initial ingestion of a larger volume of ice fragments, followed by continuous ingestion of smaller ice fragments as the normal shed characteristics are restored.

Large Birds. The requirements of FAR Parts 25 and 33 pertaining to bird impact are based on the likely consequences of the impact. For example, the empennage must withstand the impact of an eight-pound bird because the consequences of an empennage failure are almost certain to be catastrophic. On the other hand, windshields are not required to withstand the impact of a bird larger than four pounds because, even though one pilot might be incapacitated by a windshield failure due to a bird strike, the other pilot could safely land the airplane. Similarly, FAR Part 33 does not require testing of a turbojet engine with a bird larger than four pounds because the consequences of striking a larger bird are not likely to prevent continued safe flight and landing. This conclusion is based on service experience to date with large bird strikes to conventional engine and propeller designs which has been satisfactory. Therefore neither FAR Part 33 nor Part 35 require consideration of birds in this weight category.

Review of the FAA's aircraft engine bird ingestion study (reference FAA Technical Center Report, DOT/FAA/CT-84/13, A Study of Bird Ingestions Into Large High Bypass Turbine Engines, dated September, 1984) permits the conclusion that there is a reasonable likelihood of transport aircraft encountering birds weighing approximately eight pounds. Due to the contra-rotating, multi-blade configuration of the propfan engines, the likely consequences of a propfan engine failure due to bird impact must be assessed. If such a failure is likely to be catastrophic, a special condition should be proposed to require engine certification testing with an eight pound bird. For example, an 8 pound bird strike to the propulsor blades should not cause blade clashing resulting in multiple blade loss exceeding that demonstrated to be safe in the propulsor blade out test.

It is appropriate to apply the FAR § 33.77 engine medium bird ingestion requirements to the unshrouded propulsor blades. The engine bird ingestion requirements should be based on the sum of the propulsor unit area and the core inlet area.

6. Pitch Control System. The propfan powerplants incorporate pitch control devices which have not yet been described in detail to the FAA, but can be categorized as complex and unconventional based on preliminary design information. The pitch control systems include complex mechanical elements, as well as electric and hydraulic components, imbedded internally within the aft engine module in some designs. Operation of the variable pitch system will be commanded by a full authority digital electronic control, a device which has not been previously certificated by the FAA as a propeller control. Synchronization and command of dissimilar collective blade pitch between rotors are additional functions which increase the complexity and criticality of the pitch control system.

During the engine certification program, test requirements should be imposed which provide reasonable assurance of the integrity of the pitch control system. Such testing is necessary to assure protection against certain specific conditions which could potentially present a hazard to the aircraft. These include prevention of uncommanded fine pitch, particularly when attendant with an inhibited overspeed protection system, generation of excessive drag due to uncommanded flat or reverse pitch, inability to feather the propulsor blade, and uncommanded feather. The FAR Part 35 contains specific design and test requirements for the pitch control system and service experience has been satisfactory with contemporary designs which met these criteria. Therefore, testing prescribed in FAR Part 35, or appropriately similar tests, should be adopted as an element of the engine certification program as needed. Obviously, any radical departure from present design philosophies, or exposure to unusual environmental conditions, should be considered in evaluating the pitch control system test requirements.

Additionally, a thorough fault analysis should be conducted, and experimentally verified if necessary, to evaluate the impact of failures of the pitch control system. This evaluation should include assessment of single failures of hydraulic, mechanical and electrical components as well as likely combinations of failures, and failures in combination with undetected faults. The concept of analyzing the system to determine the consequences of these faults is consistent with §§ 33.75 and 33.27, which require a detailed safety analysis and determination of the speed at which to conduct the 5 minute overspeed demonstration.

7. Propulsor Drive Systems. One propfan powerplant design incorporates counter-rotating turbines to drive the propulsor blades while another uses a reduction gear system. At power levels exceeding 10,000 shaft horsepower (SHP), the gear system represents a substantial power increase over presently certificated turbo-propeller gear systems. Gear system rotating components, and those components reacting the various radial and thrust loads, will be highly loaded elements requiring preservation of close tolerances throughout the operation envelope and power regime. In conventional designs, bearings gears, turbine disks, and hubs are relatively small, sturdy and resistant to deformation. However, these components in the propfan drive systems will be larger and may be more prone to distortion associated with thermal gradients and high loads. Therefore, adoption of component endurance tests, in addition to the full-scale endurance test, may be appropriate.

For gear systems, the subject test should encompass a reasonable number of combinations of power and blade pitch, uniform and asymmetric thrust conditions between rotors, reverse operation, operation at extreme oil temperature and pressure levels, inertia loads due to gyroscopic maneuvers, and other pertinent load conditions. It is feasible that such a test program may be conducted on a full scale engine, but the complexity of the test program suggests a rig facility may be more appropriate.

In addition to these component tests, a fault analysis, as prescribed for the pitch control system, should be conducted to evaluate the ramifications of certain failures, e.g. drive decoupling. The integration of the pitch control system with the gear system or counter-rotating turbines may warrant a fault analysis which encompasses these modules as a single entity, rather than conducting independent analyses.

8. Evaluation of Distorted Airflow. The classical method of prescribing a maximum inlet distortion profile for an engine, as typically described in the engine installation instructions, is not easily applied to the propfan propulsor blades. Perturbations and asymmetries of airflow and pressure during ground and flight operations are further complicated by variabilities in blade pitch, aircraft angle-of-attack, and by transient upstream disturbances associated with various flap/slat/spoiler positions. For these reasons, a comprehensive flight stress survey must be conducted to evaluate blade/retention system stress levels during actual operations. Data generated by the flight stress survey will be necessary for propulsor fatigue evaluation per FAR Part 33 and FAR Part 35, as well as for propulsion system evaluation per FAR Part 25. For this reason, test plan review and approval, test witnessing, and data review should involve precoordination activities with the cognizant FAA offices.

The installed engine stress survey should encompass ground operations in various wind conditions, reverser operation, rotors with variations in blade cyclic/collective pitch angles (if possible), positions of various upstream wing lift devices, and Mach Number effects.

9. Propulsor Life Management Program. In recognition of the complexity and potential criticality associated with failure of the propulsor system, conservative certification requirements to supplement FAR Part 33 have been established within this report. Nevertheless, an equally conservative service monitoring program is recommended for the propulsor system, in order to evaluate the real-world phenomena of multiple daily operations in various ambient conditions, altitude effects, various pilot operating techniques and aircraft-induced effects. Therefore, a service monitoring program incorporating recurrent analytical disassembly of propulsor units removed from service at prescribed intervals would be valuable. This program will identify areas where corrective action is necessary, and may ultimately result in a hard-time, time-between-overhaul (TBO) limit or trend monitoring program with prescribed maintenance intervals. In either program, it is suggested that the program and its requirements be described in a service bulletin, or similar document, and approved by the certification authorities.

c. Environmental Issues

This section presents the current status of FAA policies and rulemaking activities related to the noise certification of propfan-powered airplanes and emissions requirements for propfan engines. Although the primary thrust of this report is to examine airworthiness issues, noise and emissions requirements are directly or indirectly involved in the overall certification process and must eventually be addressed by both the FAA and affected parts of the aviation industry. However, it must be emphasized that this report and the recommendations contained herein do not constitute or provide for a legal basis for additional environmental or airworthiness requirements. Any requirement beyond those presently codified must be promulgated under federal rulemaking procedures with full opportunity for industry and public comment.

The FAA sought an Advance Notice of Proposed Rulemaking public comment on the need for modifications to current noise and emission standards as they apply to propfan engines and propfan-powered airplanes. After consideration of the comments received, the FAA issued a Notice Decision (54 FR 19498, May 5, 1989). With respect to noise, as a result of the issues raised by many of the commenters, further consideration of both the original and commenter-identified issues, and consultation with both national and international experts, the FAA determined that the most appropriate course of action was to discontinue the rulemaking and instead, conduct the analysis specified by the Noise Control Act)of 1972) as required by Section 611 of the Federal Aviation Act. The FAA determined that further information was necessary to support the Noise Control Act analysis. Accordingly, the FAA entered into an accelerated joint research program with NASA and industry to study propfan-related atmospheric propagation, human response, community response, and economic reasonableness and technological practicability. Upon receipt and analysis of the final research results, the FAA will determine whether to initiate a new rulemaking action with an NPRM. With regard to emissions, the FAA determined that the current EPA emissions standards, and the FAA rules governing their application, are adequate for application to propfan engines and propfan-powered airplanes and that further rulemaking actions are not required.

SUMMARY OF RECOMMENDATIONS

The various recommendations made in the discussion section of this report regarding certification requirements for propfan propulsion systems and aircraft are summarized below. These recommendations apply to currently envisioned airplane configurations with aft mounted propfans in a pusher configuration. Also, the word "blade" as used herein refers to propfan propulsor blades.

a. Part 33 of the FAR, Airworthiness Standards: Aircraft Engines. The FAR Part 33 should be the base regulation for type certification of the integrated or single module propulsion system, plus special conditions as necessary for novel or unusual design features or to incorporate appropriate requirements of other regulations. FAR Part 35 may be used as the base regulation for certification of separate, stand alone, propulsor modules with special conditions as necessary for novel or unusual design features or to provide for proper integration with the entire powerplant.

b. Part 25 of the FAR, Airworthiness Standards: Transport Category Airplanes. The FAR Part 25 should be the base regulation for certification of propfan powered transport airplanes, plus special conditions for novel or unusual design features. In those areas where traditional means of showing compliance with existing requirements are inadequate or inappropriate for propfan powered airplanes, new methods of showing compliance must be devised.

c. Design precautions should be taken to minimize the hazards to the airplane in the event a blade fails or a complete blade is released. This includes consideration of the impact of the blade on vital systems and the capability of the airplane structure to survive the unbalance resulting from loss of a blade. The capability of the airplane to continue safe flight and landing following multiple blade loss shall be assessed. This assessment shall be limited to reasonably postulated multiple blade loss conditions.

d. The airplane should be capable of surviving the structural damage that would result from the impact of a blade fragment or objects likely to be deflected by the propfan blades. The size of the blade fragment to be determined from analysis of possible blade failure modes.

e. Because of the lack of containment inherent with propfans, design measures should be taken to minimize the possibility of failure or release of blade(s). These measures include an overall conservative design with ample margins between maximum operating loads and component structural and fatigue strengths adjusted for in-service deterioration and freedom from flutter. Appropriate sections of FAR Part 35, such as the blade retention test and the fatigue limit test requirements should also be met. Current FAR Part 25 requirements for an in-flight stress survey for propeller aircraft should be applied to propfan installations considering variations in pitch, airspeed, and distortion, for example.

f. In addition to compliance with the requirements of FAR § 33.75, it shall be demonstrated that the powerplant can tolerate the effects of imbalance resulting from the failure or release of a blade. The size of material released should be specific to the design configuration selected.

g. In addition to the ingestion requirements of FAR § 33.77, to determine the worst conditions, the powerplant certification program should include consideration of ingestion of airframe components likely to be liberated during the flight regime, such as nacelle doors and panels, and tire treads. A test may be required if these considerations are more severe than the large bird demonstration.

h. Design precautions should be taken to prevent the loss of airplane components located ahead of the propfan which may be more critical than those accounted for during the type certification testing for the propfan propulsion unit.

i. Specific design requirements should be imposed for positive cowling retention (means to ensure that doors remain locked; hinge design, human factors, etc.).

j. During the powerplant certification program, a large bird strike on the propulsor should be considered. If such a strike can cause a catastrophic failure, testing with an 8 pound bird should be required. Current requirements for medium bird ingestion should be applied to the entire powerplant.

k. There should be appropriate clearance between the propfan rotor and the ground when the airplane pitches up to the angle where the tail skid or aft fuselage is touching the ground, and when the aircraft is rolled during takeoff or landing to the greatest extent expected in service.

l. The propfan blades and their retention structures should have sufficient integrity to allow for the detection of a fire and the safe shut down of the engine without allowing a hazardous structural failure of the blades or their retention structures to occur.

m. In those areas of FAR Part 25 where the operating speed/altitude envelope for turbojet/turbofan powered airplanes differ from those for turbo-propeller powered airplanes, the propfan powered airplane should comply with the turbojet/turbofan requirements, including § 25.145(c). The installation should comply with either the instrument requirements of § 25.1305(d) for turbojet-powered airplanes or those of § 25.1305(e) for turbopropeller-powered airplanes as appropriate for the particular propfan powerplant model installed. In other areas, the turbo-propeller requirements would apply. Regulatory action should be initiated to clarify which operational requirements in Parts 91, 121, 125, and 135 are applicable to propfan powered airplanes.

n. The airplane should have engine restart capability following in-flight shutdown of all engines.

o. Exposure to environmental conditions such as sunlight, heat, humidity, and fluids (fuel, oil, hydraulic, deicing, and cleaning fluids) should not affect the structural integrity of the blades.

p. Blades exposed to exhaust gases must be designed to account for the exhaust stream environment on the blades during normal operation, including abnormal starts; and, the blades should be able to withstand the impact of debris from internal engine failures. Damage may exceed serviceable limits but there must be no evidence of imminent failure.

q. Lightning strikes should not cause a hazard to the blades or affect the safe functioning of the propfan.

r. Propeller pitch change requirements of FAR Parts 25 and 35 should apply to propfans. Additionally, a fault analysis is required to evaluate the impact of failures of the pitch control system. This evaluation should include assessment of single failures of hydraulic, mechanical, and electrical components as well as likely combinations of failures.

s. The endurance, durability, and fatigue characteristics of the counter-rotating turbines or the gear system incorporated in the design, should be substantiated by appropriate component testing, fatigue analysis and tests, as well as fault analysis.

t. The complex and novel design features of the propulsor systems reviewed to date indicate a need for a specialized service monitoring/sampling/on-wing maintenance program, to assure continued propulsor reliability and durability in revenue service until such time as experience indicates less restrictive measures can be permitted.

u. As a consequence of the statutory requirement for a Noise Control Act finding before an original type certificate for the airplane may be issued, enroute noise characteristics should be evaluated to provide the necessary data for the noise finding determination.

APPENDIXES

APPENDIX 1.

Dear Mr. :

Propfan or unducted fan (PF/UDF) propulsion system concepts have been the subject of research since the mid-1970's. Recently, development of these propulsion systems has accelerated to the extent that, within the next 18 months, at least three flight test programs will be initiated to study various PF/UDF prototype systems (i.e., counter-rotating, single pusher vs. tractor) in wing and aft mounted aircraft configurations.

During discussions with my staff and representatives of industry, the following items have become increasingly evident:

a. Corporate decision dates for program initiation and subsequent application for Federal Aviation Administration (FAA) type certification of aircraft and engines utilizing PF/UDF technology have moved forward. Originally, target dates were set in the 1990/1991 time period. In recent meetings, decision dates have been mentioned in late 1987 or early 1988.

b. In addition to the technical issues being discussed, concern has been expressed over what new regulatory requirements (including noise and emission requirements) or certification procedures, if any, the FAA may require for PF/UDF propulsion systems.

In view of the above, a special FAA review team has been established. The purpose of the team will be twofold: First, it will meet individually with companies, other U.S. Government agencies, and airworthiness authorities of other countries currently involved in PF/UDF programs to discuss the key technologies involved and to ask their views on possible certification or safety issues. Second, once these visits have been completed, the team will use the information collected to evaluate current airplane, engine and propeller airworthiness standards, as well as aircraft noise and emission standards with respect to PF/UDF propulsion systems certification.

The team consists of one representative from each of the following FAA organizations: The Office of Airworthiness, the Transport Airplane Certification Directorate, the Engine and Propeller Certification Directorate, and the Office of Environment and Energy. The team will draw on the expertise of various aircraft certification offices, Washington headquarters, and directorate staff throughout the review and report writing process. The team plans to develop and publish its preliminary report, with recommendations and conclusions during the second quarter of 1987, for public comment. It is our intention to hold a public conference, open to all interested persons, to review the team's preliminary report before we finalize our action plan for regulatory or procedural changes.

If you wish to participate in this effort by meeting with the team, please designate a contact person (name and telephone number) with your organization so that a visit can be arranged. The person you designate will be contacted by the team leader, Mr. Manual M. Macedo, AIR-110, (202) 267-9566, to make arrangements for a visit to your facility. The Aircraft Engineering Division is the focal point for this effort.

Sincerely,

M.C. Beard
Director, Aircraft Certification Service

APPENDIX 2

Organizations Visited/Consulted

National Aeronautics and Space Administration
Lewis Research Center, Cleveland, OH

Aerospace Industries Association
Washington, D.C.

Air Transport Association
Washington, D.C.

Civil Aviation Authority
Redhill, Surrey, England

Direction General de l'Aviation Civile
Paris, France

Netherlands Department of Civil Aviation
Amsterdam, The Netherlands

Luftfahrt-Bundesamt
Braunschweig, West Germany

Transport Canada
Ottawa, Ontario, Canada

Douglas Aircraft Company
Long Beach, CA

Boeing Commercial Airplane Company
Seattle, WA

Rohr Industries
Chula Vista, CA

Aerospatiale
Toulouse, France

British Aerospace
Hertfordshire, England

Fokker, B.V.
Amsterdam, Holland

Allison Gas Turbine Division
General Motors Corporation
Indianapolis, Indiana

General Electric
Evendale, OH

Motoren-und Turbinen-Union (MTU)
Munich, West Germany

Pratt and Whitney
United Technologies
East Hartford, CT

Rolls-Royce Limited
Derby, England

Societe Nationale D'Etude et de Construction
de Moteurs D'Aviation (SNECMA)
Paris, France

Dowty-Rotol Limited
Gloucester, England

Hamilton Standard
United Technologies
Windsor Locks, CT

Hartzell Propeller Products Division
TRW Aircraft Components Group
Piqua, OH

NOTICE

Copies of this report are available on written request to the U.S. Department of Transportation, Utilization and Storage Section, M-443.2, 400 7th Street, SW., Washington, DC 20590

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